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Use of crushed and washed overburden for stowing in underground mines: a case study

This paper throws light on the laboratory studies carried out to investigate the suitability of using overburden rocks produced from opencast mines of Ramagundem area (RG-III and RG- IV) as a stowing material for nearby underground mines of SCCL. This papers also provides a brief overview on the design of flowsheet for the processing of overburden rocks, to produce stowing material of the desired quality.

Introduction

The reserve of river sand, the traditional stowing material used in Indian coal mines, is getting depleted due to over exploitation in civil works and low rate of replenishment due to construction of dams. As a result, though river sand has proved as the best natural material for stowing, its availability within economically transportable distance from the mines is never assured. Coal seams earlier developed in bord and pillar method or other methods of underground mining had been standing on pillars for long in absence of stowing material causing mammoth loss of coal and its conservation. Amongst the various alternatives to sand as the fill material for mines, the first choice has been the overburden rocks from closely located opencast mines due to their ready stock at practically no price and cheaper transportation cost.

In India crushed stone for underground stowage had been used in the limited scale primarily because there was easy availability of river sand in the past, non-availability of indigenously manufactured crusher and hence its spare parts and also non-availability high wear resistant pipes for reticulation of crushed overburden hydraulically to underground mines. But the situation, has undergone a sea change in the current scenario due to scarcity of sand as a stowing material and being faced in almost all the coalfields in India. Angarpathra and Digwahdih collieries in Jharia appear to have started hydraulic stowing with crushed stones for the first time in the country in the year 1946-47.

At many places, worldwide, special sand stone quarries have been opened up primarily for supplying stowing materials to underground mines. The underground coalmines of The Singareni Collieries Company Ltd. are also facing the acute shortage of river sand for stowing. The study was undertaken with the view to determine various stowing related parameters of overburdens of OC-I, OC-II and OC-III and design a suitable fill quality material. A suitable flow sheet for processing overburden rock to produce the fill quality material at different rated capacities was also developed.

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Sample collection and preperation

Samples of overburden material were collected from three locations viz. OC -I, OC-II and OC-III. The samples collected were segregated into three categories, namely boulders (–250mm+150mm size), gravels (-150mm+25mm) and composite laboratory sample (-25mm) as shown in the Table 1. From transportation, fragmentation and handling point of view, OB collected from OC-III was found to be most feasible.

Preparation of Sample

In the laboratory the composite sample of each OC was mixed thoroughly and representative sample was prepared by coning and quartering method. For laboratory investigation four types of representative samples were prepared viz. composite sample (as received), washed at 53 micron cut off size, 106 micron cut off size and 150 micron cut off size.

Design criteria

The suitability of any stowing material depends mainly on the operational and safety requirements of coal mines. Depending upon the method of working, mining cycles, safety requirements and the role the fill is going to play in different geo-mining environment, generalized stowing norms have been established. River sand, the most commonly used stowing material in the coal-mining sector, fulfills all the operational and safety requirements. Therefore, to design a suitable fill quality material from overburden samples, all its stowing related parameters were determined in the laboratory and the results were compared with that of the river sand to assess the suitability. The following stowing parameters are determined:

(a) Physical properties viz., specific gravity, bulk density, porosity and grain size distribution.

(b) Water percolation characteristics.

(c) Settlement characteristics.

(d) Compressibility characteristics.

TABLE: 1: OVERBURDEN SAMPLES COLLECTED FROM OPEN CAST MINES

Location	Gradation (%)		
	- 250mm+150mm (Boulders)	-150mm+25mm (Gravels)	-25mm (Composite)
OC-I, dragline dump between 3A and 3B seam	13%	12%	75%
OC-II, OB dump of crushed material	16.9%	43.69%	49.18%.
OC-III, OB bench between 3A and 3B seams	24%	15.2%	60.8%

Characteristics of overburden vis-à-vis river sand

PHYSICAL CHARACTERISTICS

Specific gravity

The results of specific gravity of overburden samples and river sand are shown below (Table 2):

TABLE 2 : SPECIFIC GRAVITY OF DIFFERENT OVERBURDEN SAMPLES AND RIVER SAND

Type of sample	Specific gravity
OC-I	2.51
OC-II	2.57
OC-III	2.51
River sand	2.56

Bulk density and porosity

Table 3 shows the bulk density and porosity of different OB samples and river sand.

In the composite samples the bulk density of OC-III is highest and the porosity is lowest. The water retention capacity will be least in this case. The bulk density, however, decreases with washing of the samples. The bulk density and porosity of sand is comparable to the washed samples. Similarly the porosity increases with washing and the washed samples have identical porosities to that of river sand.

Grain size distribution

The maximum size of a grain in the fill should be less than 1/5th of the pipe bore with a view to limiting the critical velocity of flow in a pipeline during its hydraulic transportation. The fill material should also not contain foreign material as well as large percentage of oversize fractions so as to pose screening and pipe blockage problems. Presence of excess of fines would pose problems related to slow settlement of fines in the voids and low percolation of water through the stowing barricades.

The results of sieve size analysis as received samples (composite sample), washed samples and sand are shown in Tables 4(a) to 4(d).

TABLE 4(a): GRAIN SIZE DISTRIBUTION OF DIFFERENT OVERBURDEN COMPOSITE SAMPLES

Sieve size (microns)	% passing (Composite samples)		
	(OC-I)	(OC-II)	(OC-III)
5000	100.00	100.00	100.00
3350	95.06	99.20	95.21
2360	93.48	96.00	92.61
1180	87.94	85.40	84.63
710	77.27	68.00	69.26
500	54.35	44.00	46.71
300	28.66	23.00	22.95
250	26.28	21.40	21.56
150	15.42	14.20	13.17
106	10.67	11.00	9.58
75	7.71	9.00	6.99
53	1.58	4.00	2.59
0	0.00	0.00	0.00

TABLE 4(b): GRAIN SIZE DISTRIBUTION OF DIFFERENT OVERBURDEN WASHED (>53 µ METER) SAMPLES

Sieve size (microns)	% passing (Washed samples >)		
	(OC-I)	(OC-II)	(OC-III)
5000	100.00	100.00	100.00
3350	99.70	99.20	95.21
2360	98.68	96.00	92.61
1180	92.41	85.40	84.63
710	78.24	68.00	69.26
500	53.54	44.00	46.71
300	25.61	23.00	22.95
250	21.56	21.40	21.56
150	9.21	14.20	13.17
106	4.66	11.00	9.58
75	2.43	9.00	6.99
53	0.40	4.00	2.59
0	0.00	0.00	0.00

TABLE 3: BULK DENSITY AND POROSITY OF DIFFERENT OB SAMPLES AND RIVER SAND

Type of sample	Bulk density (gm/cc)/Porosity (%)			
	OC-I	OC-II	OC-III	Sand
Composite sample	1.59/36.67	1.77/31.10	1.84/26.67	1.54/40.00
Washed sample (above 53 micron)	1.59/36.67	1.71/33.33	1.59/36.67	
Washed sample (above 106 micron)	1.51/40.00	1.63/36.67	1.51/40.00	
Washed sample (above 150 micron)	1.51/40.00	1.54/40.00	1.51/40.00	

TABLE 4(c): GRAIN SIZE DISTRIBUTION OF DIFFERENT OVERBURDEN WASHED (>106 μ METER) SAMPLES

Sieve size (microns)	% passing (Washed samples >)		
	(OC-I)	(OC-II)	(OC-III)
5000	100.00	100.00	100.00
3350	100.00	100.00	100.00
2360	98.42	97.59	97.03
1180	90.91	84.32	85.76
710	76.09	64.82	65.58
500	49.80	38.49	38.48
300	19.57	14.17	14.54
250	17.39	12.76	12.76
150	5.34	4.32	3.86
106	0.59	0.90	0.89
75	0.20	0.30	0.30
53	0.10	0.10	0.10
0	0.00	0.00	0.00

TABLE 4(d): GRAIN SIZE DISTRIBUTION OF DIFFERENT OVERBURDEN WASHED (>150 μ METER) SAMPLES

Sieve size (microns)	% passing (Washed samples >)		
	(OC-I)	(OC-II)	(OC-III)
5000	100.00	100.00	100.00
3350	99.80	100.00	99.80
2360	97.75	96.97	96.58
1180	89.99	83.45	82.90
710	74.87	61.25	62.58
500	48.31	31.18	36.02
300	15.22	8.58	11.47
250	12.97	7.16	9.86
150	1.33	0.71	1.61
106	0.31	0.30	0.60
75	0.20	0.20	0.20
53	0.10	0.10	0.10
0	0.00	0.00	0.00

It is observed that the finer fractions (below 150 microns) constitute 15.42%, 14.20% and 13.17% in the composite samples of OC-I, OC-II and OC-III respectively. In case of river sand it is only 1.3%. However, the percentage of –150 microns decreases on washing the samples at different cut off sizes viz. –53 microns, -106 microns and –150 microns. The results indicate that only upon washing the samples at –150 micron cut off size, the values match that of sand. Therefore, removal of these fines is necessary from stowing point of view. The results also indicate that stowing quality material to the tune of 63% from OC-I, 45% from OC-II and 52% from OC-III overburdens can be produced after suitable processing.

WATER PERCOLATION CHARACTERISTICS

80-85% of water in the river sand percolates out through the barricade within an hour of placement. The pack gets consolidated, does not remain in fluid state for a long time and prevent build up of high hydrostatic heads at the barricades. So the percolation rate conforming to the above result is practically desired. As observed from Table 5, the percolation rate of river sand is 276.82 cm/hour. However, in case of OB, the percolation rates of composite samples of OC-I, OC-II and OC-III are 1.75, 1.07 and 2.96 cm/hr respectively which are practically nil. On washing the samples at different cut off sizes the percolation rates have been found to increase with increase in cut off size. At the cut off size of 150 micron, the percolation rates of these samples have been found comparable with that of sand.

SETTLEMENT CHARACTERISTICS

Settlement of solids in the voids after placement of the slurry is an important criterion. Faster settlement avoids clogging of the pores of the barricades and, therefore, does not cause build up of hydrostatic pressure inside the barricade leading it to rupture. It also eases drainage of water through the drainage pipes or barricades.

Fig.1 shows the settlement behaviour of different composite overburden samples. It is revealed that about 45 minutes are taken for the settlement of the particles in the composite samples. After washing the samples at 53 micron cut off size, the time required for settlement is about 5 minutes, which further decreases with increase in cut off size and reached to about 1 minute at cut off size of 150 micron. The river sand also takes about 1 minute to settle.

COMPRESSIBILITY CHARACTERISTICS

The fill should have low compressibility with a view to offer high resistance to the overlying strata against sagging and caving. This is an important characteristic for protection of surface features overlying mine workings, especially at shallow depths. The results of compressibility tests of various samples are presented in Fig.2.

It is observed from Fig.2 that compressibility, at

TABLE 5: PERCOLATION RATE OF DIFFERENT OVERBURDEN SAMPLES AND RIVER SAND

Type of material	Percolation rate (cm/hr)			
	OC-I	OC-II	OC-III	Sand
Composite sample	1.75	1.07	2.96	
Washed sample (> 53 micron)	40.57	29.57	64.18	276.82
Washed sample (> 106 micron)	163.62	155.09	165.46	
Washed sample (> 150 micron)	236.69	195.90	310.19	

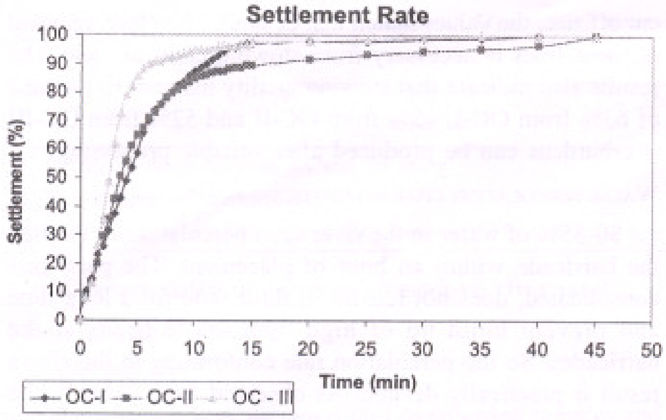

Fig.1 Settlement rates of different overburden samples

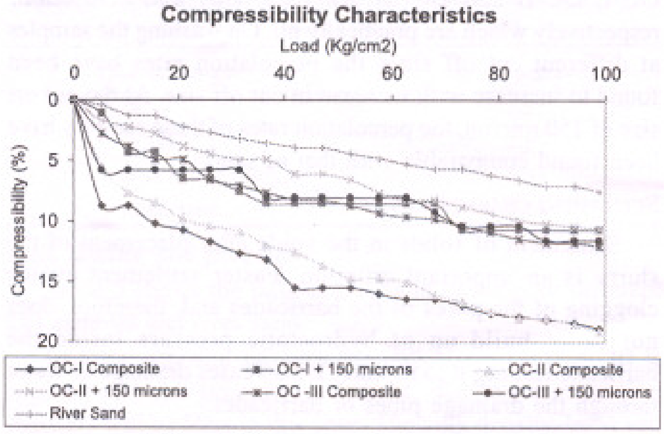

Fig.2 Compressibility of different overburden samples and river sand

100 kg/cm^2 (corresponding to a depth of 400m), of composite samples of OC-I, OC-II and OC-III OB samples are 18.9%, 19.09% and 12.02% respectively, which decreases to 10.72%, 10.58% and 11.52% respectively after washing the samples at 150 micron size. The corresponding value of compressibility for sand is 7.5%.

Flow sheet options, design and development

Flow sheet options

The laboratory study on overburden samples of OC I, II and III revealed that it can be used as a stowing material, but with slight processing so that it meets the standards of ideal stowing material. This processing will include the elimination of clayey material and keeping the size range (up to 90%) of the material within -3 to 0.15mm to improve the compressibility and drainage characteristics.

To develop the flow sheet for processing the OB material extensive data generation which included determination of grain size distribution, Hardgrove Grindability Index (HGI), Bond Work Index (BWI) etc. was carried out on OC - I, II and III samples as shown in Table 7.

Three possible alternatives appear to emerge for designing and developing the flowsheets for processing the three OB material viz. Separate flowsheets and Plants for each of the OB material or common flowsheets but separate plants or common flowsheets and common plants for each of the OB. After carrying out the data generation experiments in the laboratory, it was found out that distinct similarities existed between the crushing characteristics of the three overburden materials as is evident from the HGI and Bond Work Index values. The crushing characteristics was broadly represented by the Double Roll Crusher (DRC) product analysis as shown in Table 6. Subsequent flowsheet design and development work was therefore based on the DRC product size distribution as show in the Table 8. On evaluating the DRC product grain size distribution it was found out that 38% of the material was already within the specified size range of the stowing material, i.e. -3mm. About 26% appeared in the size range of -180mm and +3mm and the remaining ~ 36% was found to have size of +180mm. Three possible options are available to process the product of DRC to make them suitable as a stowing material for underground mines, they are as given in the Table 8.

Since about 38% of the DRC product is already finer than 3mm, option O-II is focused on using the available -3mm particles without any further crushing of the DRC product. Significance of O-II is evident as it focuses on avoiding crushing which involves capital investment in terms of operation and power consumption cost. Whereas, option O-III intends to use the entire DRC product, keeping in mind the entire requirement of the stowing material for the Ramagundam and adjoining areas of SCCL. Hence, O-III, though holistic and futuristic will require additional crushing,

Table 6: Different options for processing DRC product for stowing purpose

Options	Process
O – I	Rejecting +180 mm fraction through screen and processing -180 mm fractions
O – II	Processing only -3 mm fraction
O – III	Processing the entire DRC product

Table 7: Data generated in the laboratory for flowsheet design

Sample		D_{80}	Avg. HGI	Avg. BWI	Sp. Gr.
OC-I	As received	1000 mm	-	-	-
	Manually crushed to – 500 mm in Lab.	305 mm	63	22.01 kWh/t	2.35
OC -II	As received DRC* Product, -300mm	230	55	27.4 kWh/t	2.51
OC- III	As received	1200 mm	-	-	-
	Manually crushed to – 500 mm in Lab.	240 mm	62	19.49 kWh/t	2.63

*Double Roll Crusher installed in OC-II

Table 8: Granulometry distribution of OB material of OC-II crushed to -300mm by DRC (as received basis)

Size (mm)	Differential weight		Cumulative weight,%	
	Kg	%	Passing	Retained
+ 255	22.7	8.50		8.5
- 255 + 180	74.3	27.83	91.5	36.6
- 180 + 140	14.0	5.24	63.4	41. 6
-140 + 76	22.5	8.43	58.4	50.0
- 76 + 50	10.0	3.75	50.0	53.8
- 50 + 38	4.5	1.50	46.2	55.2
- 38 + 25	5.0	1.87	44.8	57.1
- 25 + 19	3.0	1.12	42.9	58.2
- 19 + 13	4.0	1.50	41.8	59.7
- 13 + 6.5	4.0	1.50	40.3	61.2
- 6.5 + 3	3.0	1.12	38.8	62.4
- 3	100.5	37.64	37.6	
Total	267.0	100.00	D_{80}~230mm	D_{100}=400mm

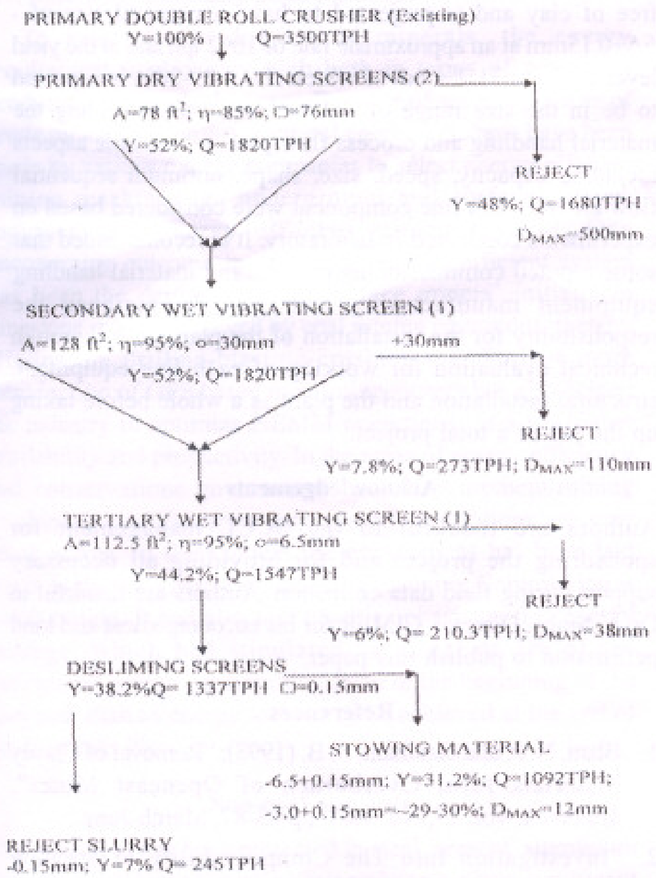

Fig.3 Process flowsheet based on already available fines in DRC product

screening and material handling arrangement which will incur considerable amount of initial capital investment and running cost but a marginal increase in output. The option O-I is neither holistic in nature nor it is able to avoid capital investment involved for crushing and operating the plant. Considering all the options in mind, it was decided to adopt O-II for designing and developing the flowsheet for processing the DRC product of OC-II

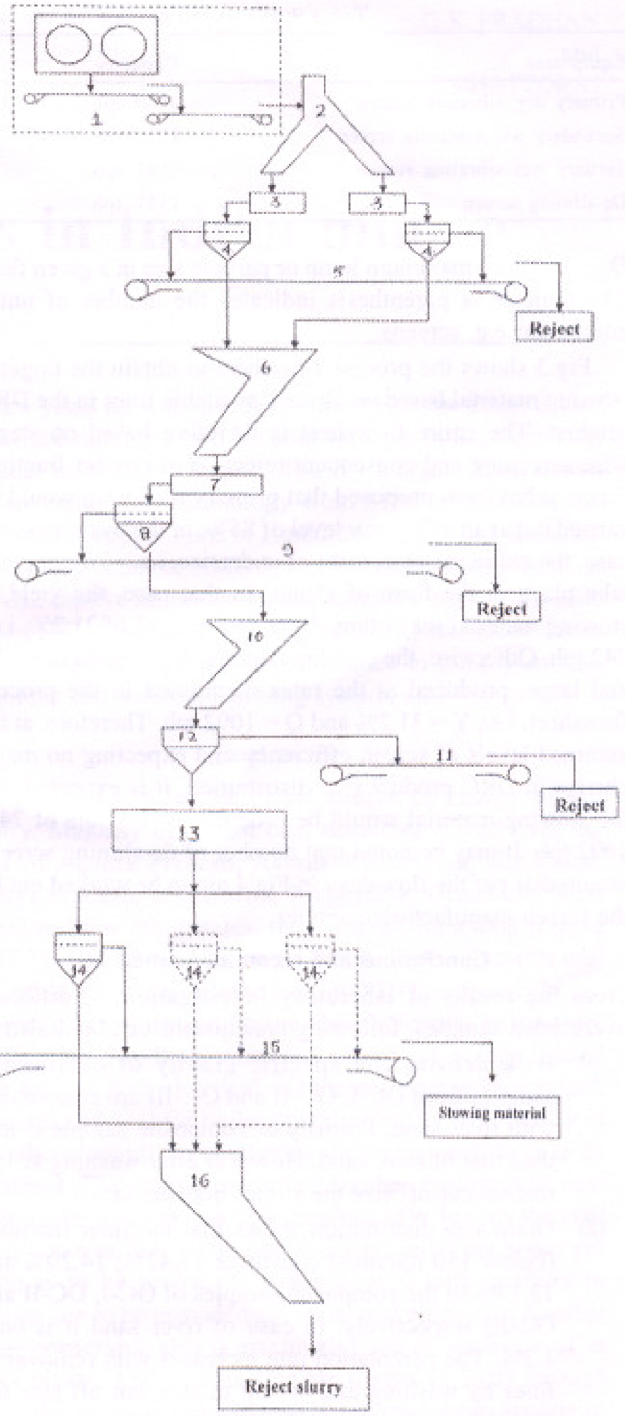

Fig.4 Material handling flow diagram based on already available fines in DRC product

Flow sheet design and development

Yield (Y) is defined as the % of feed reporting to a given product. Q indicates the flow of material in tonnes per hour (tph). "A" indicates the total screen area and η, the assumed efficiency of the screen. Two different shapes of screen apertures have been considered; square=▪ and round=O.

TABLE 9: EQUIPMENT DETAILS FOR THE PROCESS FLOWSHEET BASED ON DRC PRODUCT (FIG.1)

Equipment	Capacity	Total area, ft^2	Unit area, ft^2	Length × width
Primary dry vibrating screen	3500 tph	-150	75	J2.5×6.25
Secondary wet vibrating screen	1820 tph	-128	-128	16×8
Tertiary wet vibrating screen	1547 tph	-112.5	-112.5	15×7.5
De-sliming screen	1337 tph			

D_{max} indicates maximum lump or particle size in a given flow. The number in parenthesis indicates the number of units/equipment e.g. screens.

Fig.3 shows the process flowsheet to obtain the targeted stowing material based on already available fines in the DRC product. The entire flowsheet is therefore based on stage-wise screening and consequent rejection of coarser fraction. Since, it has been proposed that primary screening would be carried out at an efficiency level of 85%, in the worst possible case, the entire misplacement of undersize, i.e., -76 mm, may take place in the form of -3mm. In that case, the yield of stowing material may come down to the level of 21.2%, i.e., 742 tph. Otherwise, the stowing material is expected to be, by and large, produced at the rates mentioned in the process flowsheet, i.e., Y = 31.2% and Q = 1092 tph. Therefore, at the assumed levels of screen efficiency and expecting no major change in DRC product size distribution, it is expected that the stowing material would be produced at the rate of 742-1092 tph. It may be noted that number of de-sliming screens required as per the flowsheet in Fig.4 are to be worked out by the screen manufacturer/supplier.

Conclusions and recommendation

From the results of laboratory investigation on different overburden samples, following conclusions can be drawn:

(i) Bulk density and specific gravity of overburden samples from OC-I, OC-II and OC-III are comparable with river sand. Porosity of composite sample is less than that of river sand. However after washing at 150 micron cut-off size the values become same.

(ii) Grain size distribution shows that the finer fractions (below 150 microns) constitute 15.42%, 14.20% and 13.17% in the composite samples of OC-I, OC-II and OC-III respectively. In case of river sand it is only 1.3%. The percolation rate increases with removal of fines by washing and at 150 micron cut off size the percolation rates came close to that of river sand. The settlement behaviour of composite OB samples increases by washing, which becomes similar to that of sand, at 150 micron cut-off size.

(iii) The compressibility characteristics of composite samples are higher than the desired values. However, after washing the samples at 150 micron size, the compressibility of the OC samples became similar to that of any stowing material at 100 kg/cm^2 i.e. 9.8%. The corresponding value of compressibility for sand has been found to be 7.5%.

Based on the above results and discussions, it is recommended to use overburdens from OC-I, OC-II and OC-III for stowing purpose after screening out the oversize particles of +25 mm and washing them at a cut-off size of 150 micron. With this recommended processing, stowing quality material to the tune of 63% from OC-I, 45% from OC-II and 52% from OC-III overburdens can be produced.

It is recommended that a processing plant based on the flowsheet presented in Fig.3, be set up to treat the overburden rock, as obtained from the existing Double Roll Crusher product to produce a stowing material, which shall be rather free of clay and is projected to have a nominal size of -6.5+0.15mm at an approximate rate of 1092 tph and at the yield level of about 31.2% out of which about 29-30% is expected to be in the size range of -3.0+1.5mm.While deciding the material handling and process flow path, all possible aspects including capacity, speed, size, shape, optimum sequential flow etc. for each line component were considered based on experiments conducted in laboratory. It is recommended that some reputed commissioning/process and material handling equipment manufacturing firm may be assigned the responsibility for the installation of the plant with thorough technical evaluation for working of each line equipment, structural installation and the plant as a whole before taking up the job as a total project.

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